PROPOSAL FOR

SUBMITTED BY

LOCKE
INCORPORATED

IMPLSE GENERATOR INSTRUCTIONS & OPERATING PROCEDURES

Impulse Generator Instructions & Operating Procedures

Purpose

This instruction book accumulates pertinent information concerning natural and artificial lightning with the object of aiding laboratory personnel to understand and control the phenomena connected with artificial lightning generators.

The writer wishes to acknowledge the aid of publication written by members of the High Voltage Engineering Laboratory of the General Electric Company, Pittsfield, Massachusetts.

Signed

TABLE OF CONTENTS

IMPULSE GENERATOR INSTRUCTIONS AND OPERATING PROCEDURES

I. General Discussion of Lightning

Since the beginning of recorded time, lightning has been an occurrance of fear and mystery. Very little about it was known until Benjamin Franklin demonstrated that lightning was an electrical phenomenon.

With the coming of transmission lines it became more important to determine just what lightning was. At a very early time in the history of transmission lines it was noted that lightning was one of the major technical problems that had to be overcome. Since transmission lines are constructed at some height above the surrounding terrain, they are usually the most prominent object of that particular locality and therefore most susceptable to being struck by lightning. When a transmission line is struck by lightning serious damage occurs to line insulation, sub-stations, and generating equipment creating much expense and interruption of the continuity of the service that is supplied by these lines.

Over the years transmission line engineers and high voltage experts have managed to develop many types of protective devices. These protective devices such as; lightning arrestors, expulsion tubes, overhead ground wires and fast relaying techniques, have led to the term "lightning proof" transmission lines .

II. Lightning Investigations

The engineers' first studies were confined to the effect of lightning, and it was found that lightning strokes are characterized by a relatively high current flowing for a short interval of time. This means that when the transmission line is struck by lightning this fast surge of current through the impedance of the line produces a voltage drop between the line and ground. This voltage wave immediately starts to travel in both directions along the transmission line subjecting the line insulation and equipment to relatively high voltage stresses. These "traveling waves" may also be produced by induced effects from nearby strokes which do not actually contact the transmission line. By actual field investigation it has been found that the shape of these high voltage waves varies considerably.

III. Actual Lightning Waves

Wave fronts have been found to range from one to 90 microseconds to crest and from 1 to 200 microseconds duration on the tail. An analysis of these data by Bewley indicated that the majority of the fronts were from 1 to 5 microseconds and that the duration of the tail was from 10 to 40 microseconds. From this data a standard test wave described as a $1\frac{1}{2}$ x 40 microsecond wave was established by the industry so that testing could be conducted on a common basis. (Methods of defining wave shape will be explained later).

From the above discussion it becomes apparent that the $1\frac{1}{2}$ x 40 microsecond wave is not an actual lightning stroke but is a standardized voltage wave which is perhaps a little more severe than most actual lightning strokes.

In determining what magnitudes of voltage might be found to exist on transmission lines during lightning strokes it was realized that the high rate of change of current must be determined. Field investigation has shown that the current in lightning strokes may be as low as 1000 or as high as 100,000 amperes and that the rate of change of current may be as high as 40,000 amperes per microsecond, with a probable average of 4500 amperes per microsecond. From this data it is estimated that lightning voltages will range between 1 KV and 10,000 KV depending upon the impedance of the line struck.

Fortunately this voltage wave can be "chopped off" by the line insulation and only voltages having a magnitude of a little more than the critical flashover voltage of the line would reach the transformers and sub-station or generating station equipment. In addition the natural attenuation of a transmission line decreases the magnitude and lessens the severity of a stroke as it approaches sub-stations or generating equipment.

IV. Types of Lightning Waves

Since lightning waves are altered by the line insulation, expensive equipment may be subjected to three different types of waves. Waves having magnitudes slightly higher than the critical flashover value will be "chopped off" at or beyond the crest and the wave reaching the apparatus will be a "chopped wave". Magnitudes greatly in excess of the critical flashover value will be "chopped off" on the crest or before the crest. This wave when reaching the apparatus will be a "steep front" wave provided that the point of lightning stroke contact is not so distant from the apparatus as to be greatly attenuated by the time it reaches the apparatus. The other wave is the full wave in which the magnitude of the lightning voltage is less than the critical flashover of the line insulation. Therefore in laboratory tests, we attempt to duplicate these three different types of waves.

V. Wave Shape Defined

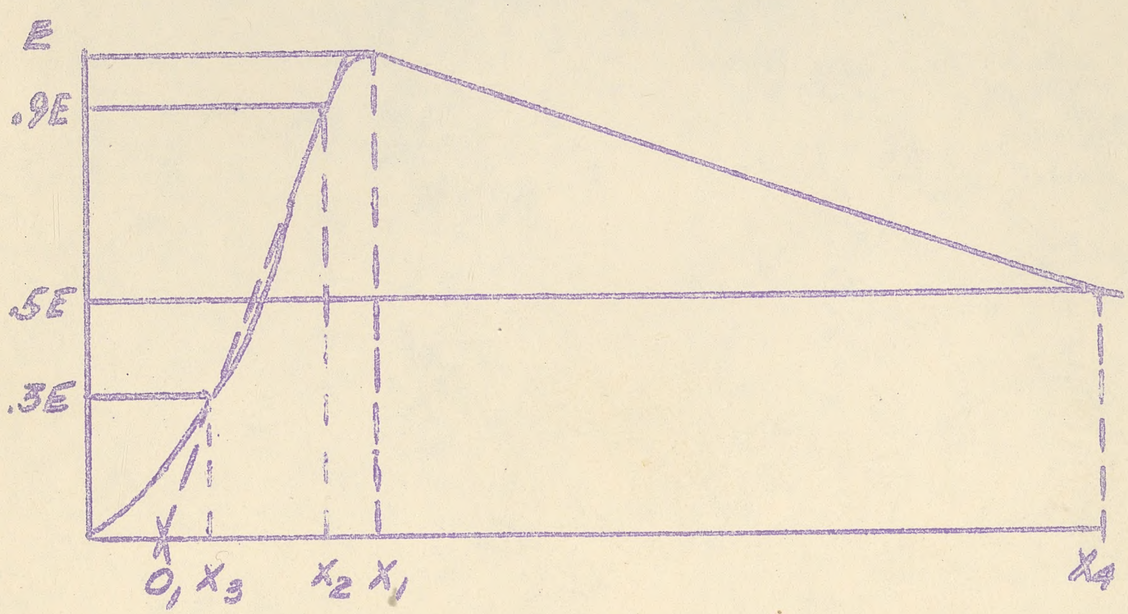
Fig. I. illustrates a typical full wave. Such waves are specified as $T_1 x T_2$ where T_1 and T_2 are the intervals O_1X_1 and O_1X_4 respectively. For practical reasons the virtual zero time is established at O_1 and is determined by the intersection of a line drawn through the .3E and .9E points on the front of the wave, with the zero axis. X_1 is the time at which the crest occurs. The time interval $O_1X_1 = T_1$ and defines the wave front.

For convenience when the crest is not clear the time of the wave front can be considered as two times the actual time interval between the .3E point and the .9E point or $T_1 = 2\ (X_2 - X_3)$.

If there are spurious oscillations on the wave front which can't be dampened out, the .3E and .9E points should be established on an average curve sketched through the oscillations.

In Fig. I. the point X_4 is established by determining the time at which .5E occurs in the tail of the wave. The time interval $O_1\ X_4 = T_2$ defines the tail of the wave.

Fig. I. Wave Shape



VI. Testing Waves

As explained in the previous section, laboratory impulse testing waves are an attempt to duplicate the different types of waves which might actually occur on apparatus due to the occurrance of a lightning stroke contacting a transmission line. Figure I illustrates these three different waves. Referring to Figure I wave #1 is a $1\frac{1}{2}$ x 40 microsecond full wave the amplitude of which is such that the wave would not cause flashover of the line insulation or apparatus bushings used with the particular voltage class of the apparatus under consideration. Such voltage amplitudes have been standardized for all common voltage classes. This means that the apparatus would have to have internal insulation with sufficient strength to withstand this full wave. Wave #2 of Figure I is an example of "chopped wave", the amplitude of which is approximately 15% higher than the full wave. In general this voltage would cause flashover of the line insulation or apparatus bushing thus producing a "chopped off" effect on the tail. On apparatus this "chopped off" effect may be produced by gaps or the apparatus bushing. The third wave, the "steep front" wave, gives rise to a somewhat special test. This is the steep front wave shown by wave curve #3 of Figure II. Such a wave is roughly 60% higher than the full wave but of very short duration. This type of wave is only experienced on transmission lines which do not provide lightning arrestors or other protective devices. When these operating practices are adhered to, voltage waves much in excess of the critical impulse flashover value of the line insulation, when occurring at or near the apparatus, will produce the steep front wave even if spilled gaps are used. This type of wave is a much more severe wave than either of the other two types. Therefore, this operating procedure in which lightning protective devices are not used, can only be justified on an economic basis where continuity of service is not of prime importance.

Figure II

Types of Lightning Waves

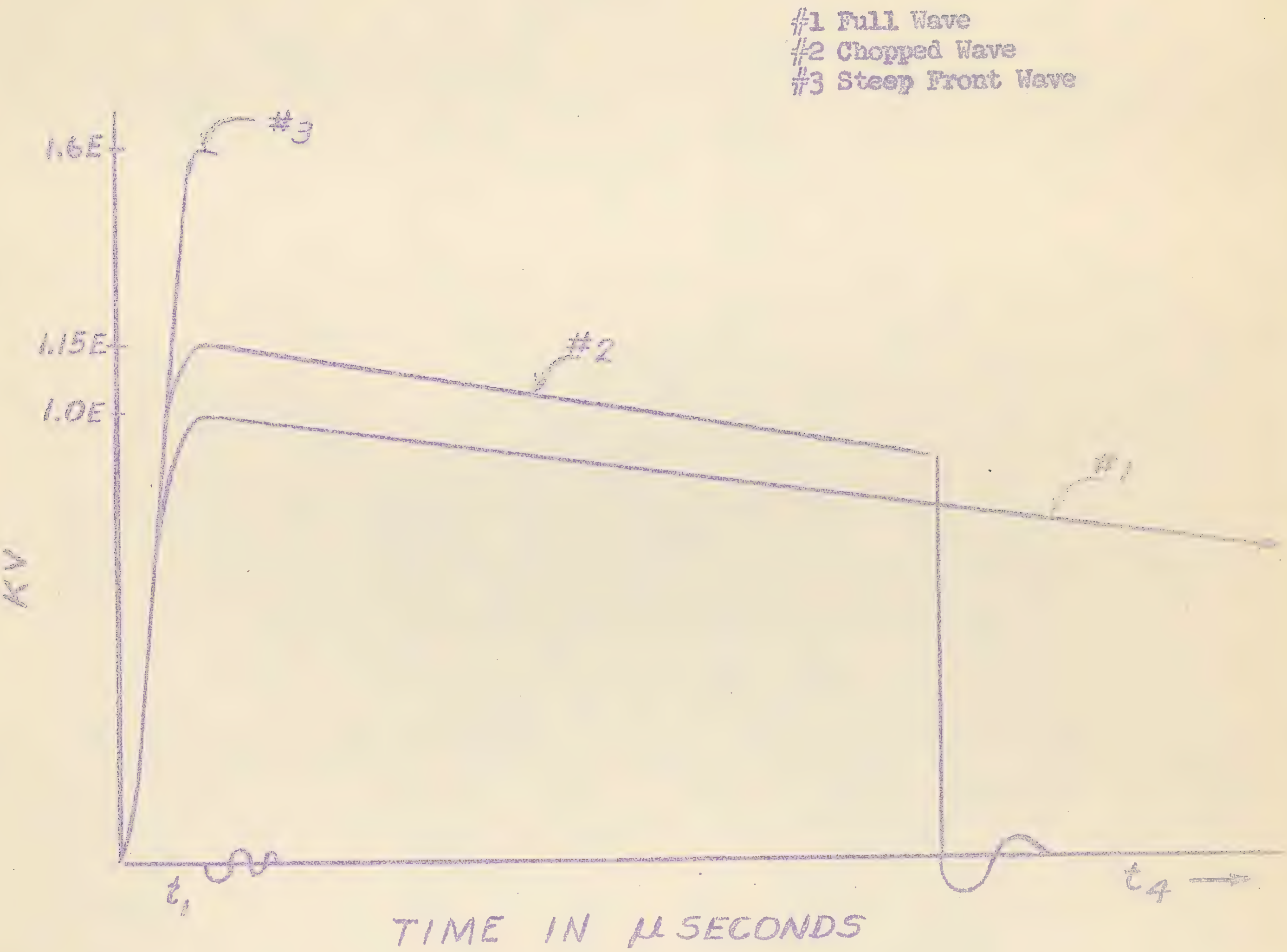
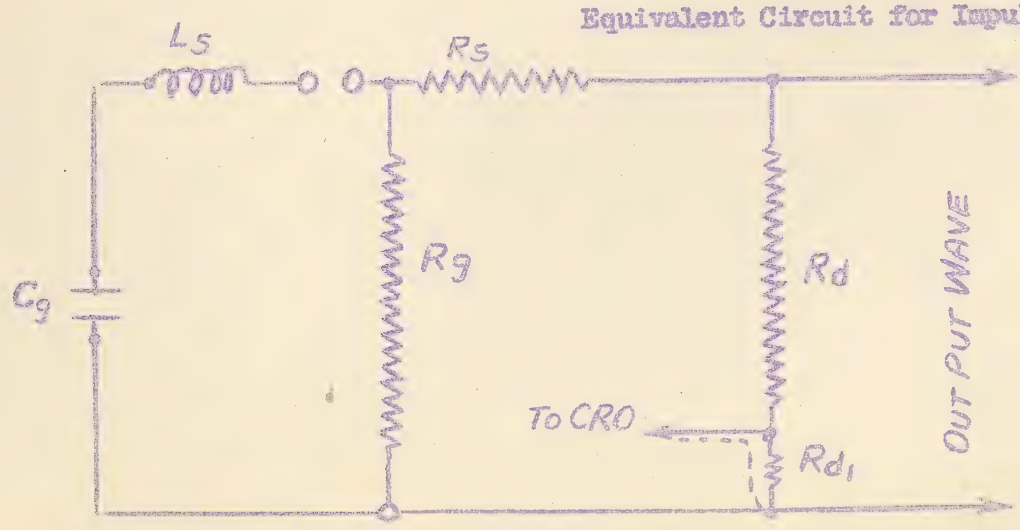


Figure III

Equivalent Circuit for Impulse Generator



VII. Artifical Lightning Circuits

The laboratory lightning generators which made possible the production of an artifical lightning stroke are essentially a discharge of a capacitor. Most generators in use today are modified Marx's circuit generators. By using a series resistance between the capacitance of the generator and the impedance of the apparatus under test and by using shunting resistors the wave shape applied to the test piece may be controlled and made to conform to the commercially standardized $1\frac{1}{2} \times 40$ microsecond wave. A typical equivalent circuit for an impulse generator is illustrated in Figure III. The impulse generator itself is represented by the capacitance (C_g) the inductance (L_g) and the isolating gap (g). In the actual circuits C_g is made up of many capacitors connected in series by many gaps. L_g is also distributed among the capacitors. The remainder of the equivalent circuit is to shape the output of the generator into the standard $1\frac{1}{2} \times 40$ wave. The resistances R_d and R_{d_1} are resistance voltage dividers whose function is to produce a reduction in the voltage magnitude so that the impulse wave can be recorded by a cathode ray oscillograph. R_g is a shunting resistor which aids in the control of the tail of the wave.

After the impulse generator capacitance (C_g) has been charged by a DC voltage to some predetermined value, the series gap (G) is made to spark over, thus causing the impulse generator to discharge into the rest of the circuit. The output voltage (the voltage across the test specimen, load capacitor, and the voltage divider) rises until the load capacitance and the impulse generator capacitance are essentially at the same voltage. This is the crest voltage and the part of the wave up to this point is called the wave front. Beyond the crest the impulse generator capacitance C_g and the load capacitance C_L act in parallel and discharge through the series resistance R_s and voltage divider resistance R_d and wave tail shaping resistance R_g. This portion of the wave is called the wave tail.

VIII. Calculations for Wave Front

The wave front is determined by the RC time constant of the load capacitance (C_L) and the series resistance (R_s), the self inductance (L_s), and the impulse generator capacitance (C_g) (Appendix I gives the theoretical calculation for wave fronts and wave tails. From this it can be shown that, provided the series resistance (R_s) is sufficiently large to prevent oscillation on the crest of the wave, the equation for the time to crest is approximately 2.5 times the RC constant of the output circuit. Where C is the effective series capacitance of the generator capacitance (C_g) and the load capacitance (C_L) or where C is equal to $C = \dfrac{C_L\, C_g}{C_L + C_g}$. In other words, the wave front time in microseconds equals 2.5 times R_s times C. The minimum value of R_s can be determined from the equation for critical dampening or R_s minimum is $2\sqrt{L_s/C}$. In actual practice it is found that the load capacitance (C_L) is only about 1% to 10% of the generator capacitance (C_g) therefore the equation for wave front may be reduced to time of wave front in microseconds (t) is equal to 2.5 $R_s\, C_L$ in microfarads. The constant 2.5 is theoretically obtained by assuming that the voltage built up across (C_g) the generator capacitance (C_g) remains constant during the time to the crest value. Obviously this is an error since the generator capacitance C_g starts to discharge the instant that the gap (G) breaks down. Since the constant 2.5 is dependent upon a discharge rate of C_g it is obvious that the length of the tail will have an effect upon this constant.

IX. Calculations for Wave Tail

As soon as the load capacitor reaches crest value, the generator capacitor (C_g) and the load capacitor (C_L) immediately start to discharge through the effective resistance shunting them. In the type of wave shaping circuit used in the Locke High Voltage Laboratory in which an R_d, R_s, and R_g are used the effective shunting resistance is considered to be the parallel combination of R_d plus R_s and R_g. Since C_g is much greater than C_L the discharge current is considered to split at the junction of R_s and R_g. Therefore, the equation for effective shunting resistance is a $R = \frac{R_g (R_s + R_d)}{R_g + R_s + R_g}$. From Appendix A we find the equation for time of wave tail (t_2) is $t_2 = 0.7R (C_g + C_L)$.

X. Voltage Regulation

In operating an impulse generator it is desirous to know the approximate regulation which will occur in the output circuit. Two types of regulations take place. One is the effective ratio of the capacitance of the generator and the capacitance of the load circuit, the other the voltage divider effect of the combination between R_s and R_d. The generator output E_c in terms of the capacitance regulation is $E_c = \frac{E_o C_g}{C_g + C_L}$. Where E_o is equal to the charging voltage of the generator times the number of capacitors and E_c is the generator voltage (E_o) regulated by capacitor effects.

In considering the resistive regulation (E_r), $\frac{E_r}{E_o}$ would equal $\frac{R_d E_o}{R_s + R_d}$. Therefore, in terms of both $\frac{E_r}{E_o}$ and $\frac{E_c}{E_o}$ the output regulation $\frac{E_r}{E_o} = \frac{C_g}{C_g + C_L} \cdot \frac{R_d}{R_s + R_d}$

This equation is not precise, however, for most modern generators using the $1\frac{1}{2} \times 40$ microsecond impulse wave it gives a very close approximation. The error is due to neglecting the series inductance of the circuit which causes additional voltage rise at the crest.

XI. The Locke Impulse Generator Circuit

The 3,000,000 volt impulse generator now in the High Voltage Laboratory of the Locke Department, G.E. is indicated schematically in Figure IV. The generator consists of the following main parts. Induction regulator, rectifier, capacitor bank, wave shaping resistors, and a trip unit.

In normal operation power is supplied to the induction regulator which varies the input voltage to the rectifier transformer. The DC output which is placed across C_1 and C_2 is obtained from a voltage doubler type of circuit using two kenetron tubes (V_1 and V_2). The operation of this rectifier set is as follows: At any given positive half cycle of the excitation voltage, V_2 will conduct through the capacitor C_2 and the transformer by means of the charging resistors R_{co} and R_{c1}. During the negative half cycle of the excitation voltage V_1 will conduct placing a charge across C_1 by means of the rectifier transformer and the charging resistors R_{co} and R_{c2}. In this manner during the charging up period a positive charge will be placed on one side of each group of capacitors and the negative charge will be placed upon the other.

The charging resistors R_{c1}, R_{c2} --- R_{cn} allow the capacitors to charge on a relatively long time constant but issolate them during the discharge of the generator; Caution: Inasmuch as the capacitors C_1 and C_2, etc. are individually rated at 75 KV DC, the lower side voltage of the rectifier transformer input should be limited to approximately 360 volts.

If the trip gap T_g were now to be short-circuited, the generator would fire in the following manner. When T_g closes, point (1) would be reduced from some positive potential to a ground potential. This pulse would travel through C_2 and C_1. Point (2) would now have twice the negative potential than what it had while the generator was charging. This would increase the voltage gradient across G_1 causing it to break down. It then follows that the voltage at point (2) would be placed at point (3) causing a further reduction in voltage at point (4), causing G_2 to break down and so on. In this manner, through its internal gaps, the voltages across the individual capacitors of the generator would be added up and discharged through the final gap into the

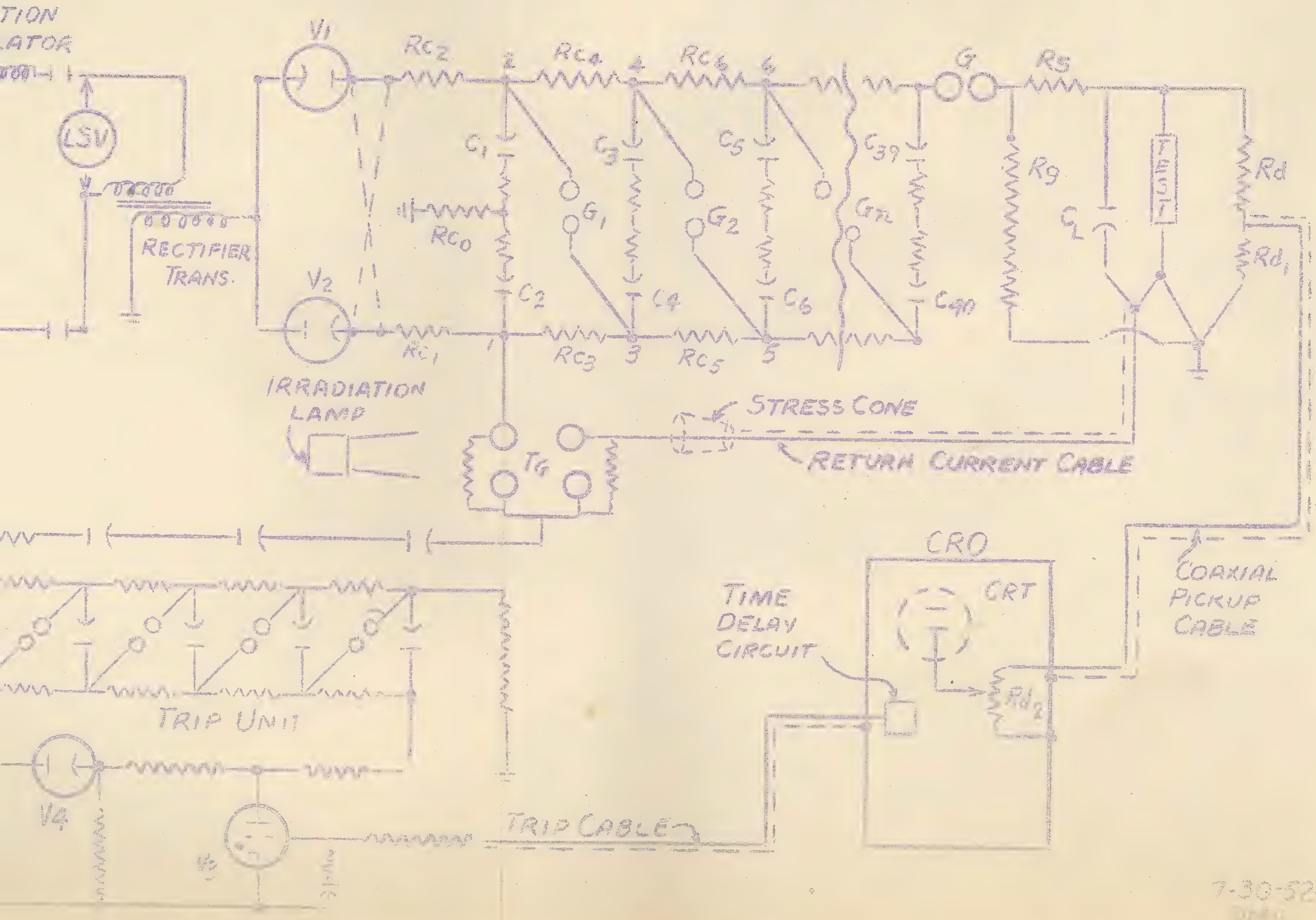
wave shaping circuit consisting of R_s, R_g, R_d, R_{d1}, and C_L placing the output voltage across the test specimen.

In actual practice the gap T_g is short-circuited by means of the trip unit. The trip unit is essentially another small impulse generator which has an output voltage of approximately 62-1/2 KV. One end of this small trip unit is grounded through the tube V_3 which is a hydrogen filled thyraton. The 62-1/2 KV pulse is placed upon the gap (T_g) which upsets its gradient sufficiently to break down the center gaps. The grid of V_3 is triggered by a pulse from the time delay circuit of the CRO. This rather complicated firing mechanism is essential in that reliable control of the instant the generator fires is desirous since that time must be synchronized with the start of the horizontal sweep on the CRO.

A positive output voltage on the impulse generator may be obtained by changing the output connections of V_1 and V_2 as shown by the dotted lines in the schematic diagram of Figure IV.

FIG. II

IMPULSE GENERATOR SCHEMATIC DIAGRAM



7-30-52

FIG. IV
IMPULSE GENERATOR SCHEMATIC DIAGRAM

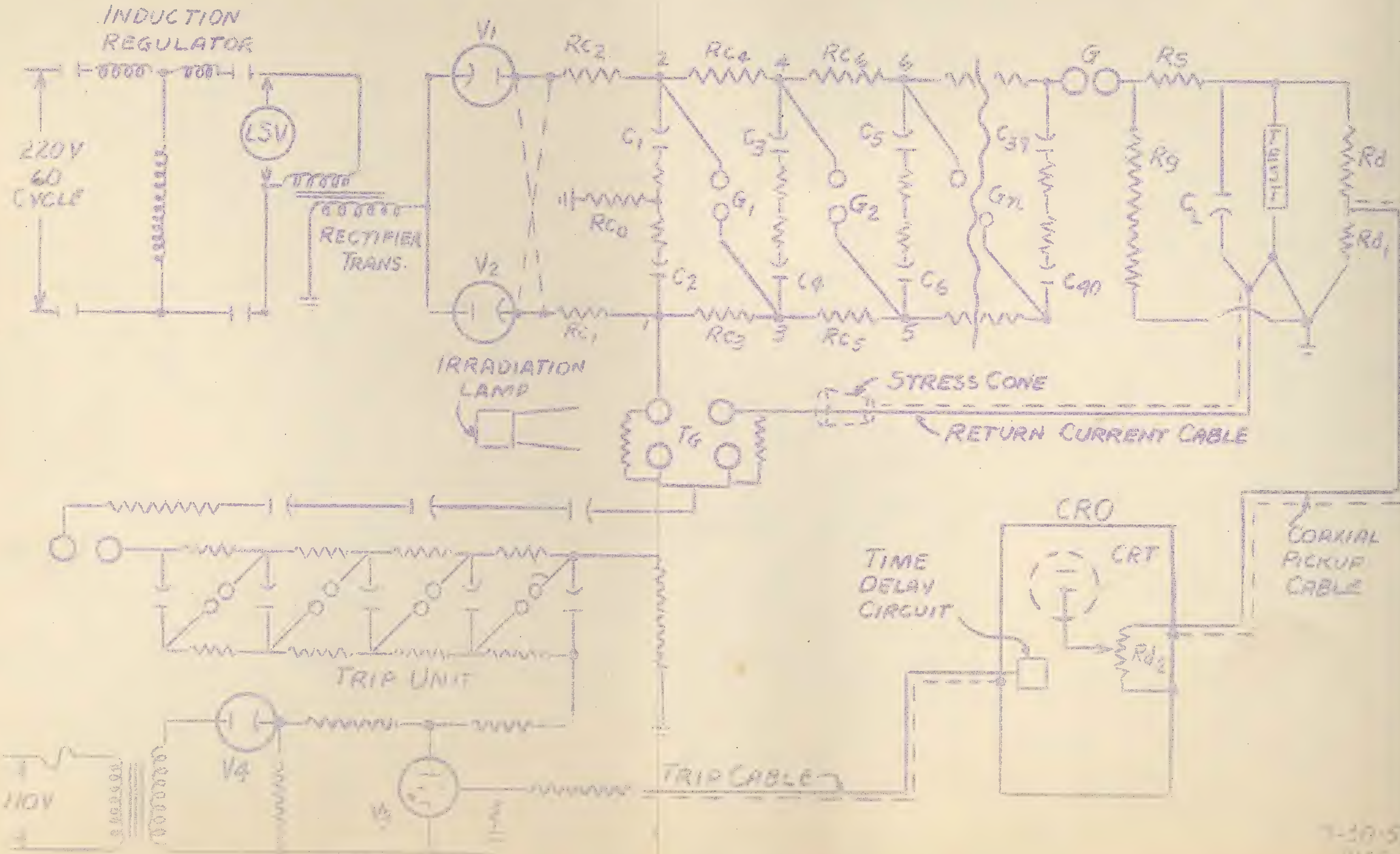
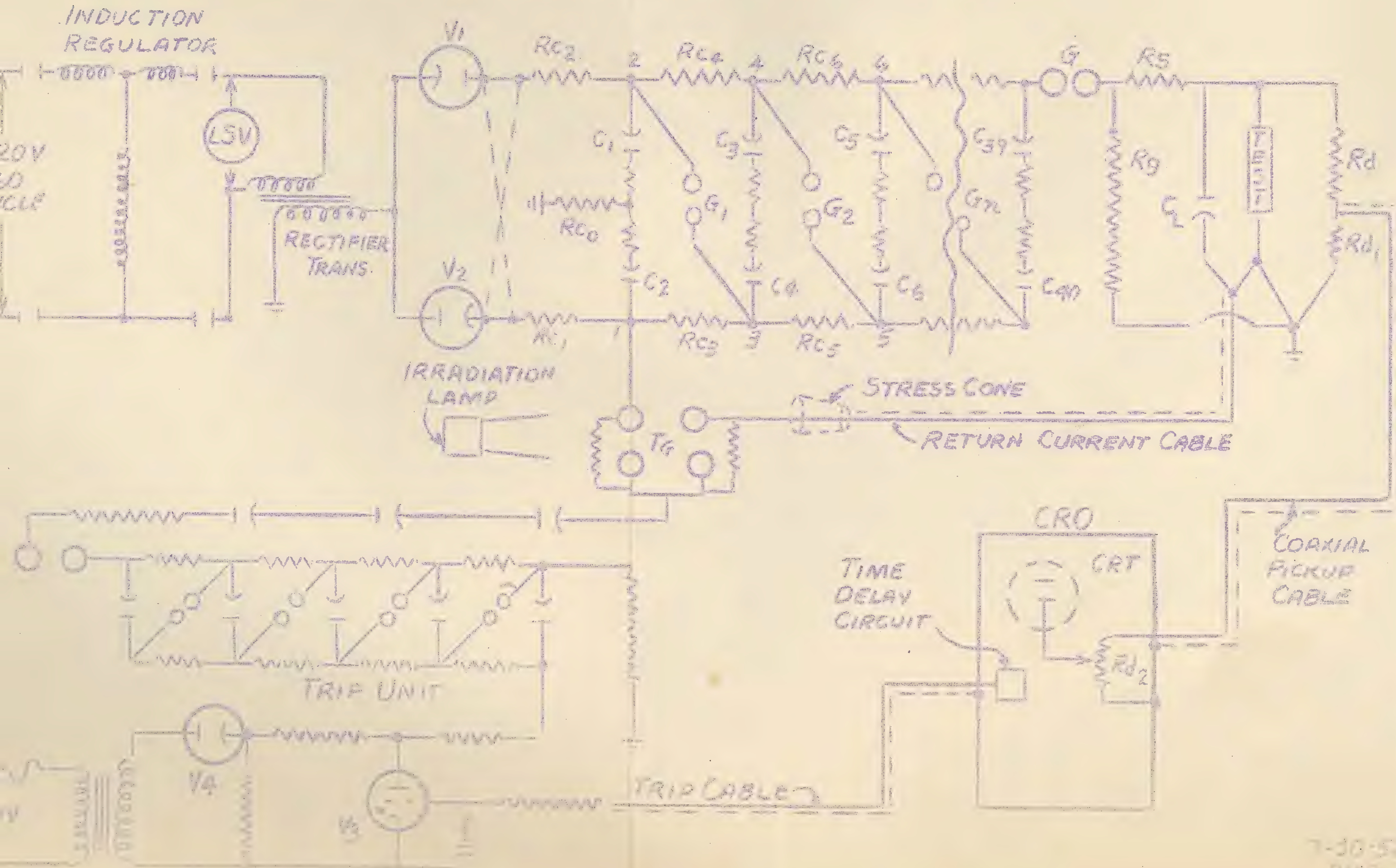


FIG. II.

IMPULSE GENERATOR SCHEMATIC DIAGRAM



7-30-52
DWG

XII. Voltage Dividers

Since there is no known method of accurately measuring high voltages directly, some type of voltage divider must be used. Several types are in use today. These are the capacitance dividers, the compensated dividers and the resistance dividers. Since the main purpose of a divider is to accurately reproduce a voltage shape in miniature the magnitude being reduced by a value equivalent to the voltage divider ratio, extreme caution must be observed in obtaining this ratio. The capacitance divider is greatly affected by stray capacitance and therefore must be calibrated by the use of a resistance divider. The compensated divider, while found to be experimentally very effective in that it attenuates all frequency to the same degree, is not too practical because it becomes extremely large at higher voltages. The resistance divider is favored by most laboratories within the G. E. Company as it is the most flexible and when used properly gives the best result. The resistance voltage divider must be kept well away from the influence of the generator field otherwise it would be a partially compensated divider. The RC time constant of the divider must be kept to a small enough value so that the waves placed across them are not distorted on the output end. The resistors used in this divider must be as highly non-inductive as possible. Every attempt must be made to uniformly grade the applied voltage across these resistors, and again, the voltage divider ratio must be stable and capable of being accurately determined. All connections must be tight because any spurious discharges would distort the wave shape and change the voltage gradient on the resistors creating a transient change in divider radio. The resistance values of the component parts of the voltage divider must be very accurately determined. This measured resistance value must be checked against the calculated resistance inasmuch as the non-inductively wound resistors might have one side open giving twice the rated resistance across this particular card. When the high voltage is impressed across this card, the small break will spark over giving the rated value of resistance, therefore, the measured resistance value would not be the true value under operating conditions.

The voltage divider ratio is equal to VDR = $\frac{R_d}{R_d + R_o}$ where R_o is equal to the parallel effective resistance of R_1 and the terminating impedance R_2 of the co-axial pick-up cable. In selecting the proper size of voltage divider, two things must be considered. The minimum time to be measured and the maximum voltage to be impressed across the divider. The maximum voltage per resistor card should not exceed 50 KV and the total value of the resistance divider should correspond with the values as indicated in AIEE Standards No. 4, Revised, Paragraph 4-163.

XIII. Cathode Ray Oscillograph

The cathode ray oscillograph is an instrument containing various DC power supplies, timing waves, sweep circuits and other associated control equipment, all built to operate an evacuated tube containing an electron beam emitter (cathode) focusing electrodes, deflection plates and accelerating plates (anodes).

If a voltage which varies linearly with time is suddenly impressed upon the horizontal deflection plates of the CRT and the voltage wave to be measured is impressed upon the vertical deflection plates, the electron beam will be deflected proportionally, and thus the time-voltage relationship of the wave to be measured will be plotted when these deflected electrons impinge upon a florescent screen. Photographic prints may be taken of this plot, securing a permanent record of the wave.

By means of the timing waves, DC calibration voltages, and the voltage divider ratios, the exact wave shape and magnitude may be determined.

In most testing the accuracy of the voltage magnitude as indicated by the CRO and the voltage divider ratio must be checked against the magnitude of the same voltage wave as measured by standard sphere gaps. They must not differ from each other by more than 5%. Methods of making these checks are outlined in AIEE Standards No. 4, Revised, Paragraph 4-166.

When testing and using voltages in excess of 1400 KV, the oscillograph must be solely relied upon because as sphere gaps are inaccurate in that range. Therefore, the fact that the accuracy of the CRO and the voltage divider must be maintained is emphasized.

It is highly important that the pick up cable from the voltage divider to the CRO be terminated by a value of resistance equivalent to the surge impedance of the test pick-up cable. This terminating impedance is imperative at the CRO end of the pick-up cable but is not necessary at the voltage divider end.

XIV. How to Select The Proper Standard Generator Circuit

Determine the range of voltage at which tests will be desired. Determine minimum time to flashover which will be expected. Select a standard size generator compatible with the above conditions. Standard generator curves are given in the Appendix. They have been set up so that a wide variety of the above conditions may be obtained. The particular curves are a calibration of lower side voltage versus sphere gap spark overs for $1\frac{1}{2}$ x 40 waves. The calibrations hold only as long as the exact circuitry is duplicated as given on the curve sheet. Any variation in the circuitry (Except changes in R_{d1}) constitutes a non-standard set-up and a new calibration curve must be obtained.

XV. Non-Standard Generator Circuits

When the use of a standard size generator is not feasible other types of generators may be set up by paralleling the generator capacitors, splitting up the generator, inserting internal resistance, making variations in wave shaping resistors or load capacitor.

The following rules should be strictly adhered to when setting up non-standard generators.

(a) Always maintain adequate charging resistance in the generator between all banks of capacitors.

(b) Grade all voltages as uniformly as possible. This is imperative in the case of the voltage divider as non-uniform gradients will affect the divider ratio.

(c) Do not exceed 75 KV crest per resistor card. (50 KV per card on voltage divider).

(d) Keep the inductance as low as possible by avoiding the use of long lead lengths or small diameter wires.

(e) Appearance of "over shoot" on the crest of a full wave indicates that excessive inductance is present in the circuit. This will lead to an error in the calibration.

(f) Keep the return currents separate from the grounding circuits. The high return currents if introduced in any major proportion into the ground circuit, will create $\frac{L_{di}}{d_t}$ drop in these ground leads and will, therefore, raise, above actual ground, points which should be kept at ground.

(g) Maintain generator sphere gaps in as clean a condition as possible.

(h) Metal parts of the generator should always be tied in with the rest of the circuit. Floating metal parts draw capacitive currents which will cause spurious spark-overs which have the effect of distorting the output wave. All spurious spark-overs must be avoided.

Do not exceed 2500 volts across R_{d1}.

One side of the test specimen and the ground side of R_{d1} must be kept at ground potential at all times.

XVI. Operating Procedure

An impulse generator is an expensive and highly specialized piece of equipment. In its design optimum mechanical strength has been sacrificed to enhance its electrical strength. For this reason it would not be subjected to excessive mechanical stresses of any type.

After the proper type of generator has been set up the following procedures should be followed in starting up the generator.

1. Check entire circuit for proper connections and tightness of connectors.
2. Select the proper polarity.
3. Remove both grounding and shorting straps on the condensers.
4. Throw in safety disconnect switch located on left side of the control panel.
    (a) Green light comes on indicating power available.
    (b) Green light in gate circuit signal light comes on if safety circuit selector switch located by the stairs is in the proper position.
5. Throw filament switch to start position and hold for 10 seconds then quickly change to run position.
    (a) Adjust filament voltage to red line by using fine control knob.
    (b) When the rectifier filament switch is placed in the run position, the filament on the trip unit power supply chaise are also turned on. Since a hydrogen filled thyration is used for tripping, a 5 minute time delay locks out the high voltage to the thyration to allow it to reach the proper operating temperature.
6. Turn on 110 volt switch to the oscillograph.
    (a) Be sure that the back oscillograph door is closed. The back door is interlocked with the high voltage power supply of the oscillograph.
    (b) The oscillograph contains a thermal time delay to allow it to heat up.

7. Turn on the 300V, 900V and 25 KV power supplies to the oscillograph.
   (a) Observe the CRO tube while turning on the 25 KV power supply since the tube would burn up if a failure had occurred in the 900 volt power supply.
8. Adjust the oscillograph to the proper sweep speed, timing wave, DC calibration, focus, intensity, bias and the camera to the proper aperature opening.
   (a) Excessive intensity should be avoided in that it clouds films and shortens the life of the CRT.
   (b) Use the green CRO button for tripping the CRO while making these adjustments. This button does not trip the impulse generator.
9. Close all interlock gate circuits.
   (a) A large green light located on the left-hand side of the control panel lights when all gates are properly connected and closed.
10. With the volt meter selector switch on the highest range, turn the control switch to "regulator" position.
   (a) Red light over regulator position goes on indicating that regulator is energized. Observe voltage on volt meter.
11. Check the operation of the gate circuits by opening one of the gates. The regulator contactor should trip out.
   (a) Sign safety record book to indicate the above checks and state condition of circuits.
12. Throw regulator in and adjust to the approximate lower side voltage (LSV) as determined by the standard curve of LSV verses KV for the particular generator which has been set up or from some other appropriate calibration curve.
13. Adjust the gap spacing to correspond with the LSV as per posted curve.

Note: This gap spacing is approximate and should be used only as a guide in making initial settings.

14. With the "trip-no-trip" switch in the "no-trip" position, throw the control switch to the rectifier position. This will perform the following operations;

(a) Remove the ground from the output of the rectifier set.

(b) Close the contactors between the regulator and rectifier.

(c) Turn on the high voltage to the trip unit.

(d) Switch the gate signal lights from green to red.

(e) Start the charging time timer.

Caution: If excessive regulation of the LSV is indicated, trip the circuit immediately since a short is probably on the circuit. If rapid firing of the generator occurs, the gaps are probably too close together and must be immediately opened up. Continued rapid firing will blow the 1.25 amp fuse in the trip unit power supply.

15. When the charging time buzzer signals sounds and with the CRO selector switch on the VD position, push the red surge button on the CRO. This will cause the following sequence of operation. The CRO button picks up a relay on the time delay circuit which fires a thyration which sends out two pulses. One going through a variable time delay circuit to the trip unit, the other goes through a 1 microsecond time delay cable and starts the sweep. The one going to the trip unit will short out the thyration causing the trip generator to fire and thus the main generator to fire. If all connections and adjustments are correct, you will observe the output wave of the generator on the CRO scope. If it is desired to take a picture of this wave, prior to pushing the surge button, the switch on the top of the camera holder must be closed.

16. If CRO trace is not in the center of the tube, correct by using the timing control, or bias control. If trace does not appear at all, the main gaps in the generator may be spaced too far apart in which case they should be closed down by use of the gap control mechanism.

17. The generator may be shut down automatically at the end of any one firing by placing the "trip-no-trip" toggle switch in the trip position. This switch has to be reversed to the "no-trip" position prior to starting up again.

Caution: Prior to doing any work in the impulse generator area or immediately upon entering the impulse generator area, all dangerous parts of the impulse generator must be grounded and shorted. These are (1) Normal grounding safety switches mounted on output of rectifier. (2) Grounding and shorting strap on crank mechanism for both sides of the generator. (3) Test specimens having high capacitance.

18. When re-adjusting the LSV to a different level, it should be remembered that the generator will charge to approximately the highest LSV applied, not necessarily to the final point of adjustment. For this reason it would be good practice to turn off the rectifier to adjust the LSV.

19. Data should consist of the following items; specimen information, generator set-up (if standard, the curve number may be referred to), wet and dry bulb readings, barometer reading, polarity of the generator, lower side voltage (LSV), timing wave, frequency, sweep speed, DC calibration voltage and polarity, number of the picture taken, what type of flashover occurred. For most of the testing done in the Locke Laboratory, it has been found expedient to place both timing wave and a DC calibration voltage on every exposure.

XVII. Trouble "Shooting"

Symptom #1: Regulator will not trip in.

(a) Check all gate circuits.

(b) Check position of safety circuit selector switch.

(c) Check fuses to pick up coil.

(d) Check filament switch, should be in run position.

Symptom #2: No high voltage on trip unit.

(1) Check 1.25 amp fuse. Fuse probably blew because gaps on trip generator were too close.

(2) Check 1B3 tube for proper operation.

Symptom #3: Lack of control over generator firing. The four electrode gap, although irradiated, is irregular in its performance with respect to changes in humidity. In addition, small amounts of dirt or dust will greatly change their flashover characteristics. Since a large majority of the variable time delay in firing a generator is located in these gaps, it is essential that they be clean and spaced properly. The ground side set of gaps should be spaced closer than the high side set of gaps. Prior to re-adjusting the spacing of the gaps, it should be determined whether or not the trip unit itself is operating properly. This may be done by turning the rectifier on but reducing the LSV to zero and then attempting to trip the trip unit. If the trip unit is operating properly, you should then look to the relative spacing between the large internal gaps of the generator and the four electrode gap. If the generator seems to be firing at a spacing which is quite a bit higher than that indicated on the LSV versus gap spacing curve the four electrode gaps are probably set too close. On the other hand, if it is impossible to obtain the correct timing so that the impulse can be observed on the screen of the CRO tubes, it is highly probable that there is too much delay in this gap because it is too far apart. With experience these gaps should be relatively easy to maintain in proper operating condition.

Symptom #4: No trace on tube.

1. Lack of sufficient intensity or focus.

2. Failure of 25 KV accelerating voltage. Check fuse. Failure of sweep circuit to

produce a CRO grid trip. Check sweep circuit operation by checking current jacks in chassis.

Symptom #5: Irratic firing of the generator.

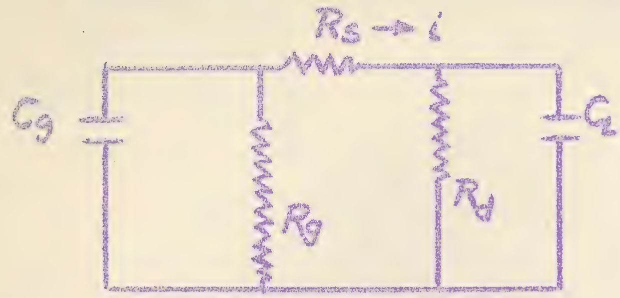
1. Clean and re-adjust all gaps.

2. Listen for capacitor breakdowns.

3. Trip unit gaps too close. Ionizing wisker too close.

Symptom #6: Poor timing between start of sweep and firing of generator. This is also probably poor adjustment of gaps and is more noticeable on the shorter sweep speeds. Check irradiation for proper operation. Check thyrations of time delay circuit.

DERIVATION OF AN APPROXIMATE FORMULA FOR FRONT OF WAVE CALCULATION.



C_L = Load Capacitance

C_g = Generator Capacitance

R_s = Series Discharge Resistance

R_d = Voltage Divider Resistance

Figure I

Discussion of Circuit

Since C_g is much greater than C_L and R_d is much greater than R_g which is much greater than R_s, and since the time for the voltage across C_L to reach crest is very small compared to the total discharge time of C_g, the circuit can be assumed to take the form of Figure II. Inductance is very small and so is neglected.

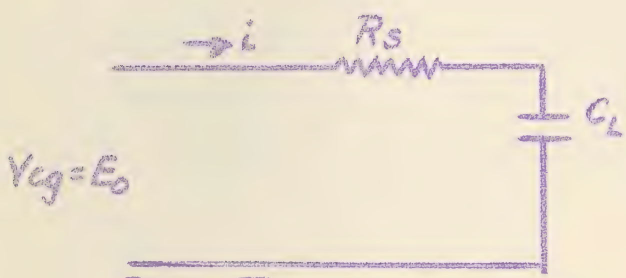


Figure II

Here the load capacitance is charged from a constant potential ($V_{c_g} = E_o$) source through the dampening and charging resistor (R_s). This E_o is also assumed to be equal to the crest voltage that would have been obtained in Figure I.

In other words the discharging effect of R_g and R_d is neglected. Keeping Figure II and the assumption above in mind, the voltage appearing across C_L V_Ts time would appear as in Figure III.

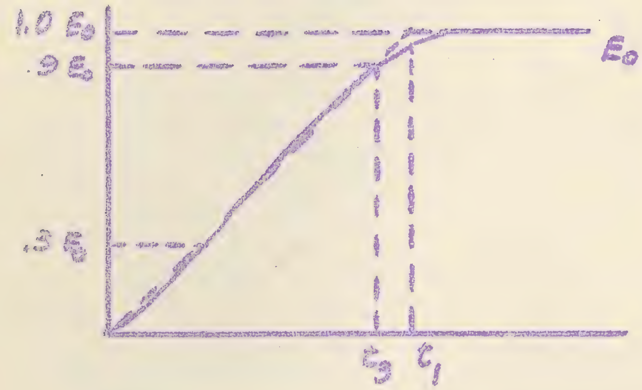


Figure III

Derivation of Wave Front Formula

At any time (t_n) the sum of the voltages in the circuit of Figure II is equal to zero.

$1/C_L \int idt + iR_s - E_o = 0$ Equation 1a

Differentiate Equation 1a with respect to t:

$i\ 1/C_L + R_s\ di/dt = 0$, or $i + R_s C_L\ di/dt = 0$ Equation 2a

This has the classical solution which takes the form.

$i = e^{mt}$ Equation 3a

$di/dt = me^{mt}$ Equation 3.1a

Substitute Equation 3a and Equation 3.1a in Equation 2a:

$e^{mt} + R_s C_L me^{mt} = 0$ or $1 + R_s C_L m = 0$

Solve for m:

$m = \frac{-1}{R_s C_L}$ Equation 4a

Substitute Equation 4a in Equation 3a and remembering that for every value of m there is a constant K to be determined from the limiting conditions:

$i = Ke^{-t/R_sC_L}$ Equation 5a

at time $t_n = o$ from Equation 1a, $i = E/R_s$

So from Equation 5a at time $= o$, $i = K = E/R_s$

Therefore at any time t_n

$i = E/R_s\ e^{-t_n/R_sC_L}$ Equation 6a

The Equation for the voltage (VC_L) across C_L at any time from Equation 1a is; $Vc_L = 1/C_L$ idt $= E_o - iR_s$ Equation 7a

Substitute Equation 6a in Equation 7a

$Vc_L = E_o - E_o/R_s\ R_s e^{-t_n/R_sC_L} = E_o\ (1-e^{-t_n/R_sC_L})$ Equation 8a

Since the AIEE standard #4 defines the virtual zero of the wave as the line through the .3 E_o and .9 E_o points and assuming that t_1 coincides with the time of crest equals E_o, we can solve for t_3 at .9 E_o, and t_1 at E_o will be proportional.

At .9 E_o E uation 8a reads, $Vc_L = .9\ Eo_o = Eo_o\ (1-e^{-t_3/R_sC_L})$

$.9 = 1 - e^{-t_3/R_sC_L}$, $.1 = e^{-t_3/R_sC_L}$

Taking the ln of both sides:

$\ln .1 = t_3/R_sC_L$

$t_3 = R_sC_L \ln .1 = 2.3\ R_sC_L$ Equation 9a

since $.9\ E_o/1.0E_o = t_3/t_1$

$t_3 = .9\ t_1$ Equation 10a

Substitute Equation 10a in Equation 9a

$.9\ t_1 = 2.3\ R_sC_L$

or

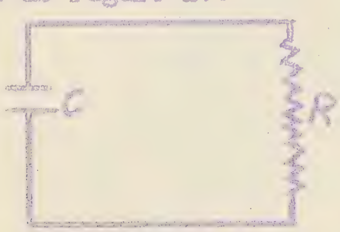
$t_1 = 2.3/.9\ R_s C_L = 2.5\ R_s C_L$ Equation 1la

The above Equation holds true for wave front provided E_o is equal to the crest value reached. This means that C_L must be small compared to C_g and that R_s is held to as small a value as possible.

The above Equation also assumed that the inductance of the discharge circuit was very small which is usually true for impulse generators. The assumption of constant E_o and small inductance are compatible because the effect, if any, of the inductance in the circuit is to keep E_o constant.

Tail of wave (discharge time)

For this calculation the equivalent circuit of Figure I would be as Figure IV.



R = Effective Resistance to Ground

C = Effective Cap to Ground Includes C_L and C_g.

Inductance is again Neglected

Figure IV

Let E_o again equal the crest voltage reached.

Then at any time t_n, the voltage (Vc) across C equals the voltage drop across R.

$$Vc = E_o = 1/c \quad idt = V_R = iR$$

$$iR = E_o = 1/C \quad idt \qquad 1b$$

The above Equation is similar to Equation 1a and the boundary conditions of $V_R = iR$ at $t = o$ is the same, therefore, the solution will be the same.

$i = E/R\, e^{-t_n/RC}$ 2b

AIEE standards #4 define the limits in microseconds of the tail as the time t_1, plus the time from t_1 to t_2 as in Figure V.

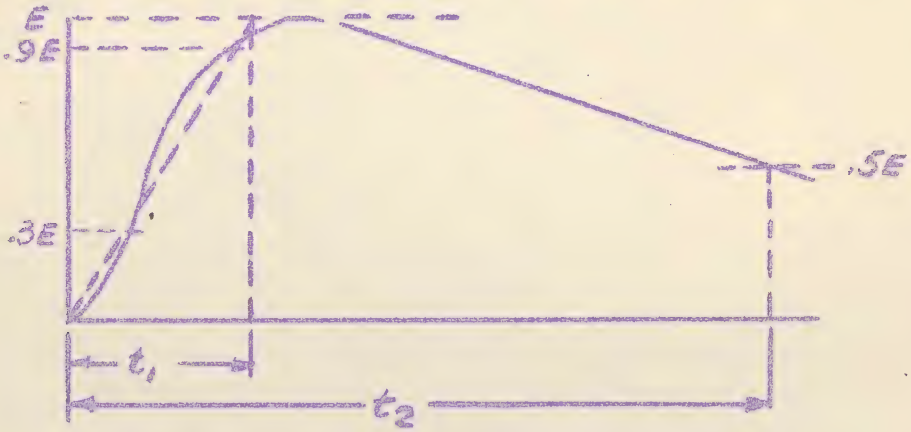


Figure V

Substituting in Equation 2b for the time when $V_R = .5E$

$i = .5E/R = E/R\, e^{-t_4/RC}$ 3b

$.5 = e^{-t_4/RC}$ 4b

$\ln .5 = t_4/RC$

$t_4 = .6932\ RC$ 5b

Since $t_2 = t_1 + t_4$

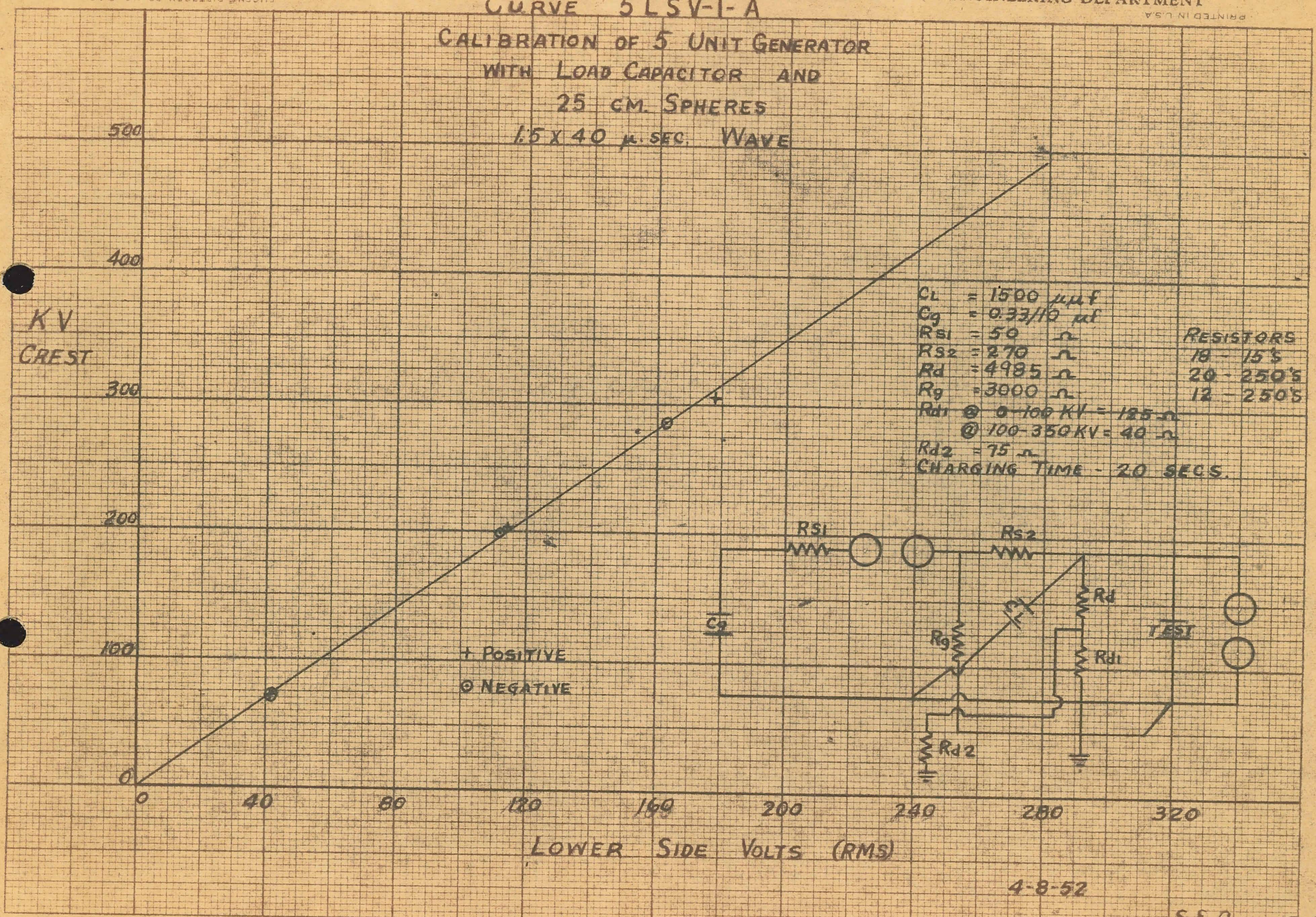
$t_2 = t_1 + .6932\ RC$ 6b

$C = C_g + C_L + C_s$ 7b

$R = R_g\,(R_s + R_g)/R_g + R_s + R_d$ 8b

then equation 6b becomes approximately:

$$t_2 = t_1 + \frac{.7\, R_g\,(R_s + R_d)\,(C_g + C_L + C_s)}{R_g + R_d + R_s}$$ 9b

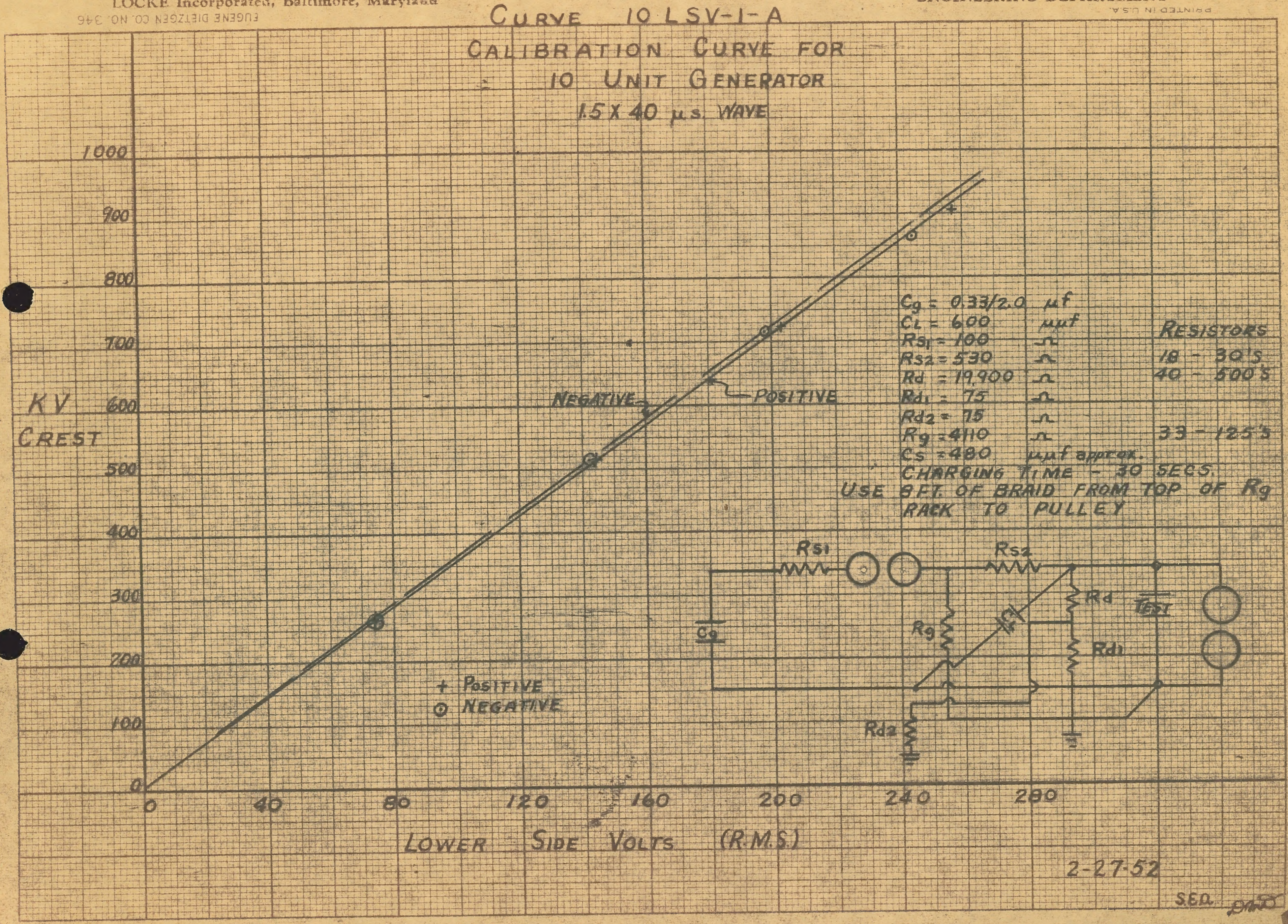

CURVE 5LSV-1-A
CALIBRATION OF 5 UNIT GENERATOR
WITH LOAD CAPACITOR AND
25 CM. SPHERES
1.5 X 40 μ. SEC. WAVE
KV
CREST
0
100
200
300
400
500
0
40
80
120
160
200
240
280
320
LOWER SIDE VOLTS (RMS)
+ POSITIVE
⊙ NEGATIVE
CL = 1500 μμf
Cg = 0.33/10 μf
Rs1 = 50 Ω
Rs2 = 270 Ω
Rd = 4985 Ω
Rg = 3000 Ω
Rd1 @ 0-100 KV = 125 Ω
@ 100-350 KV = 40 Ω
Rd2 = 75 Ω
CHARGING TIME - 20 SECS.
RESISTORS
18 - 15's
20 - 250's
12 - 250's
Rs1
Rs2
Cg
Rg
Rd
Rd1
Rd2
TEST
4-8-52
S.E.O.

LOCKE Incorporated, Baltimore, Maryland

EUGENE DIETZGEN CO. NO. 346

ENGINEERING DEPARTMENT

PRINTED IN U.S.A.

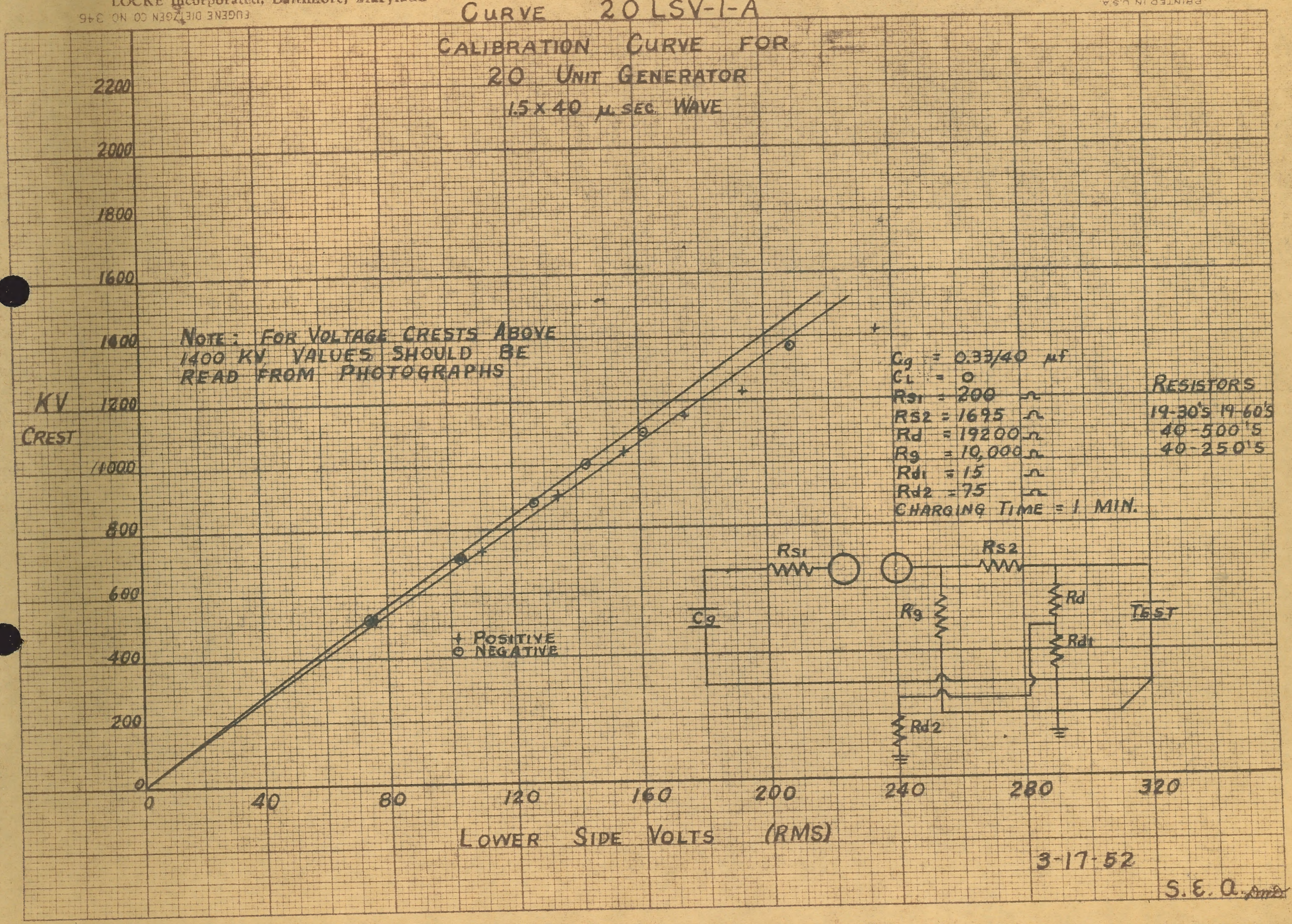


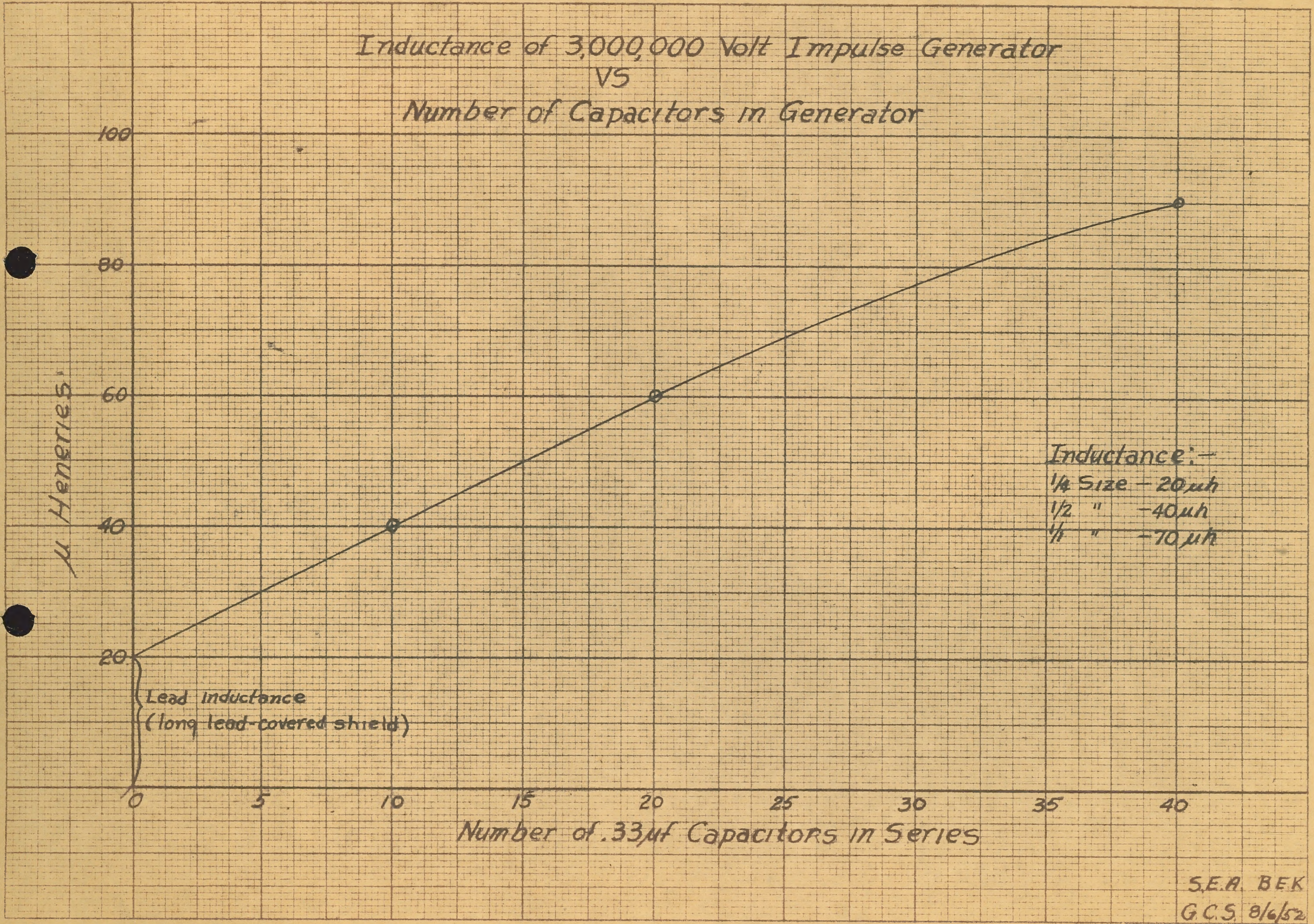
LOCKE Incorporated, Baltimore, Maryland

EUGENE DIETZGEN CO NO 346

ENGINEERING DEPARTMENT

PRINTED IN U.S.A.




Inductance of 3,000,000 Volt Impulse Generator
VS
Number of Capacitors in Generator
μ Henеries
100
80
60
40
20
Lead inductance
(long lead-covered shield)
0
5
10
15
20
25
30
35
40
Number of .33μf Capacitors in Series
Inductance:-
1/4 Size - 20μh
1/2 " -40μh
1/1 " -70μh
S.E.A. BEK
G.C.S. 8/6/52